BLIND COMPRESSED-DOMAIN WATERMARKING FOR MPEG-ENCODED VIDEOS

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1. INTRODUCTION

Image/video watermarking has been an interesting technique to solve the problem of owners' copyright protection and authentication [1]. Most of the watermarking algorithms process raw-type data and embed watermark information in the spatial [1,12] or DCT domain [2,4,9,10,11]. Basically, spatial domain methods suffer from less robustness against pirate attacks by using simple image processing. On the other hand, transform-domain methods become more popular due to their higher robustness.

Transform-domain techniques embed the watermarks into a fractional part of transform coefficients in a scheme guaranteeing successful watermark extraction. Often, the watermark energy is spread over a large number of frequency ranges before embedding so that the energy in any given range will be very small and undetectable. On the other hand, destroying the watermark would require much noise to be added to all frequency range. This kind of methods is called spread-spectrum coding [2,10,11]. Another type of methods, e.g., Koch and Zhao's [3], selects a certain number of groups of coefficients in each 8×8 DCT block and modifies them so that their relative strengths constitute two states to encode a one or zero value. Often each group may contain more than one coefficient so that noise should be high enough in order to change from one state to the other. The modification amounts can be signal-dependent so that image quality can be retained after watermarking and high robustness against external attacks can be also achieved.

Categorization of watermarking algorithms can be also according to other features. For examples, 1) visible or invisible watermark ; 2) fragile or robust watermark ; 3) raster data or compressed bit stream as the input source ; 4)

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raster data or compressed bit stream as the watermarking output ; 5) block-based or object-based scheme ; 6) public (blind) or private de-watermarking.

Basically, different combinations of the above alternatives may fit to diverse applications. For example, since most of the video exist in their compressed form (MPEG-X) for easy storage and transmission, it will be much more efficient if the watermarks are embedded directly in compression domain without fully decoding the bit streams back to pixel graylevels. Traditional watermarking methods were based on unquantized DCT domain and hence demand much more time in performing DCT/IDCT. They are also suffered from watermark removal when lossy compression via DCT quantization is encountered. The de-watermarking process may be blind, meaning that watermarks can be extracted or detected without the knowledge of original video data. This property is important and desirable in applications where a huge amount of video database is infeasible, e.g., Internet authentication.

One of the earliest watermarking techniques for DCT-based compressed images was reported by Koch and Zhao [3]. Their method facilitates insertion of watermarks while an image is currently or already compressed. Their method suffers from two shortcomings. Firstly, many of the zero coefficients in low energy blocks are changed to non-zero values, therefore increasing a considerable amount of bit rate after watermarking. Secondly, their method may make significant change of selected DCT coefficients, which will cause annoying artifacts and PSNR degradation.

Some other watermarking techniques based on compressed domain can be seen in [5-8]. Wu and Liu [5] described a data embedding method for image authentication by modifying each quantized coefficient to the closest value whose table look-up (0 or 1) is consistent with the binary watermark bit. Their method, thought maintaining a least distortion, but will be fragile subject to re-encoding attack with coarser quantization. Langelaar *et al.* [6] proposed two techniques for real-time labeling of MPEG video. The first method embeds a label by substituting specific variable length codes in the bit stream with their counterparts. This technique maintains a constant bit rate, but is prone to re-encoding attack with coarser quantization. The second method discards high frequency coefficients to cause an energy difference between two groups of blocks (each of 8 8×8 blocks), which implicitly indicates an embedded "0" or "1" bit. Their method however has the drawback of low embedding capacity. Hartung and Girod [7] performs de-quantization of DCT coefficients before being added with DCT-transformed watermark block and is actually not a compressed domain approach. The scheme proposed by Holliman *et al.* [8] selects texture blocks, by classification, to embed watermark bits by modifying two quantized DCT coefficients in each block. Their method however requires original image data to correctly select blocks which had been modifed.

An effective DCT-compressed-domain video watermarking algorithm is proposed. It requires no original bit stream data for watermark retrieval and is capable of achieving better visual quality and high robustness to re-encoding attack. In short, our algorithm will be categorized into "invisibility", "robustness", "block-based DCT domain", "compressed input source", "compressed watermarked output", and "blind de-watermarking process". The result is compared to those of Koch's method [3] to show our superiority. Both objective and subjective tests were performed to demonstrate the feasibility.

2. THE PROPOSED METHOD

In our system, MPEG-encoded video bit stream is first partially decoded to get quantized DCT coefficients. After compressed-domain watermarking, they are then re-Huffman-encoded to form a new bit stream for further applications. Since, by experiments, simultaneous disturbances on all YUV components will degrade visual quality significantly, only Y-component is adopted for watermarking. Furthermore, only I-frames are processed to retain acceptable quality. Though this might cause drift errors [7] of P-frames at the decoder side, MPEG's GOP (group of pictures, often 12 or 15 frames) structure can actually restrict errors that are possibly propagated. Watermarking on B-frames, though causing no drift errors at the decoder side, will not be adopted due to many zero DCT coefficients whose modification may result in an increase of bit rate.

To make tradeoffs between visual quality and robustness, the shaded area Ω in Fig. 1(a) expresses quantized DCT coefficients in the middle-band chosen for watermark embedding. First, notations are defined as follows.

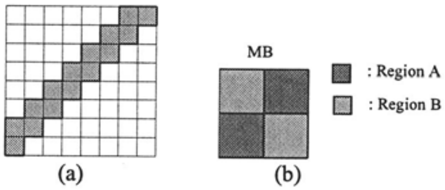


Fig. 1. (a) Region (Ω) of coefficients chosen for watermark embedding in a DCT block. (b) Partition into regions A and B for an MB.

(1) *MB* (macroblock) : 16×16 pixels as usual, a basic unit for one bit embedding, further partitioned into regions A and B, as in Fig. 1(b).

(2) $d_{QA(x,y)}(i,j)$ and $d_{QB(x,y)}(i,j)$: quantized DCT coefficients of regions A and B, where $0 \le i,j \le 7$ and (x, y) represents block coordinates in the ranges of $0 \le x < \frac{M}{8}$ and $0 \le y < \frac{N}{8}$ (assuming image frame size of $M \times N$ pixels).

(3) w : the watermark bit to be embedded in an *MB*.

2.1 Watermark Embedding Scheme

Principle of our scheme is similar to Koch and Zhao's [3] method, but different in two aspects : 1) each group contains more than one coefficient so that noise should be high enough in order to change from one state to the other, 2) with the given robustness achievable (i.e., the distance between states "0" and "1"), the manner of coefficient modification to each group will be to achieve a better image quality after watermarking. Our bit-embedding procedure in each MB is described below.

Step 1: Compute energy difference E_d between regions A and B for each MB.

$$E_d = E_A - E_B = \sum_{(k,l)\in\Omega_A} \left|d_{QA(x,y)}(k,l)\right| - \sum_{(k,l)\in\Omega_B} \left|d_{QB(x,y)}(k,l)\right| .$$

Step 2: Compute q_A and q_B to give modification quantities for nonzero coefficients in Ω_A and Ω_B, respectively.

$$q_{Ai} = \left\lceil \frac{|E_d| + \beta}{2 \cdot n_A} \right\rceil, \; q_{Bi} = \left\lceil \frac{|E_d| + \beta}{2 \cdot n_B} \right\rceil, \quad (\text{if } n_A, n_B \neq 0)$$

$$q_A = q_{Ai} + \left\lceil \frac{m_A}{n_A^+} \right\rceil, \; q_B = q_{Bi} + \left\lceil \frac{m_B}{n_B^+} \right\rceil, \quad (\text{if } n_A^+, n_B^+ \neq 0)$$

where

β : the energy margin to be conserved between E_A and E_B for robustness when encountering intentional attacks,

n_A, n_B : numbers of nonzero quantized coefficients in Ω_A and Ω_B,

n_A^+, n_B^+ : numbers of coefficients whose absolute values are larger than q_{Ai} and q_{Bi}, respectively,

m_A, m_B :

$$m_A = \sum_{(k,l)\in\Omega_A} \left| \left|d_{QA(x,y)}(k,l)\right| - q_{Ai} \right| \qquad \textit{for} \quad \left|d_{QA(x,y)}(k,l)\right| < q_{Ai}$$

$$m_B = \sum_{(k,l)\in\Omega_B} \left| \left|d_{QB(x,y)}(k,l)\right| - q_{Bi} \right| \qquad \textit{for} \quad \left|d_{QB(x,y)}(k,l)\right| < q_{Bi}$$

In the above, q_{Ai} and q_{Bi} actually compute the initial estimates of disturbing quantities that each nonzero DCT coefficient in regions A and B, respectively, should on average be incurred if both E_A and E_B are required to get a change of $E_d/2$ to eliminate their energy difference. The correcting terms, $\left\lceil \frac{m_A}{n_A^+} \right\rceil$ and $\left\lceil \frac{m_B}{n_B^+} \right\rceil$, for q_{Ai} and q_{Bi} are figured out based on the face that DCT coefficients of small magnitudes can be only incurred a change of less than q_{Ai} or q_{Bi} (e.g., -2 can be at most changed to 0, but not crossing zero to +2). This correction is to ensure that the energy difference E_d can be fully eliminated, if necessary, in following steps (e.g., cases 3 & 5 in step 3).

Step 3 : Cases of

(1) If w = "1" and $E_d \geq \beta$, then keep all DCT coefficients unchanged.

(2) If w = "0" and $E_d \leq -\beta$, then keep all DCT coefficients unchanged.

(3) If w = "1", $E_d < \beta$, $n_A \neq 0$, and $n_B \neq 0$,

then modify nonzero coefficients in Ω_A and Ω_B so that $E'_d \geq \beta$ by

$$\begin{cases} d'_{QA(x,y)}(k,l) = d_{QA(x,y)}(k,l) + q_A \cdot sign\left(d_{QA(x,y)}(k,l)\right) & if\ d_{QA(x,y)}(k,l) \neq 0 \\ \quad = 0, & if\ d_{QA(x,y)}(k,l) = 0 \end{cases}$$

and

$$\begin{cases} d'_{QB(x,y)}(k,l) = 0\ , & if\ \left[\left(d_{QB(x,y)}(k,l) > 0\right) \cap \left(d_{QB(x,y)}(k,l) - q_B < 0\right)\right] \\ & or\ \left[\left(d_{QB(x,y)}(k,l) < 0\right) \cap \left(d_{QB(x,y)}(k,l) + q_B > 0\right)\right] \\ & or\ d_{QB(x,y)}(k,l) = 0 \\ \quad = d_{QB(x,y)}(k,l) - q_B \cdot sign\left(d_{QB(x,y)}(k,l)\right)\ , & otherwise. \end{cases}$$

That is, we would like to increase E_A and simultaneously decrease E_B so as to change the polarity of their relative magnitudes.

(4) If w = "1", $E_d < 0$, $n_A = 0$ and $n_B \neq 0$,

then set all the coefficients in Ω_B to zero, randomly select two coefficients in Ω_A, and modify them to get $E'_d \geq \beta$ by

$$d'_{QA(x,y)}(k,l) = \max\left\{\left\lceil \frac{\beta}{2} \right\rceil, 1\right\},$$

This arrangement may increase the transcoded bit rate.

(5) If w = "0", $E_d \geq -\beta$, $n_A \neq 0$ and $n_B \neq 0$,

then modify nonzero coefficients in Ω_A and Ω_B (similar to case 3) so that $E'_d < -\beta$ by

$$\begin{cases} d'_{QB(x,y)}(k,l) = d_{QB(x,y)}(k,l) + q_B \cdot sign\left(d_{QB(x,y)}(k,l)\right) & if\ d_{QB(x,y)}(k,l) \neq 0 \\ \quad = 0, & if\ d_{QB(x,y)}(k,l) = 0 \end{cases}$$

and

$$\begin{cases} d'_{QA(x,y)}(k,l) = 0\ , & if\ \left[\left(d_{QA(x,y)}(k,l) > 0\right) \cap \left(d_{QA(x,y)}(k,l) - q_A < 0\right)\right] \\ & or\ \left[\left(d_{QA(x,y)}(k,l) < 0\right) \cap \left(d_{QA(x,y)}(k,l) + q_A > 0\right)\right] \\ & or\ d_{QA(x,y)}(k,l) = 0 \\ \quad = d_{QA(x,y)}(k,l) - q_A \cdot sign\left(d_{QAB(x,y)}(k,l)\right)\ , & otherwise. \end{cases}$$

(6) If w = "0", $E_d \geq 0$, and $n_B = 0$,

then set all the coefficients in Ω_A to zero and modify two coefficients randomly chosen in Ω_B to get $E'_d \leq -\beta$ by

$$d'_{QB(x,y)}(k,l) = \max\{\left\lceil \frac{\beta}{2} \right\rceil, 1\}.$$

where $sign(x) = +1$ if $x \geq 0$, and $sign(x) = -1$ if $x < 0$. The goal is to represent "0" and "1" by relations between energy terms E_A and E_B.

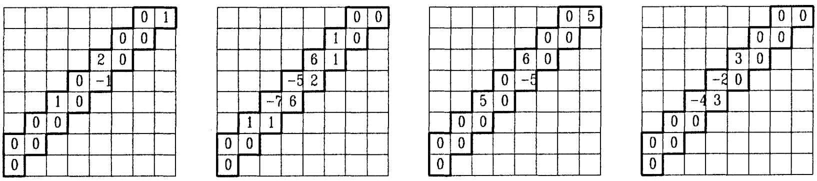
Step 4 : Re-perform zigzag scan and VLC (variable length coding) to produce the watermarked MPEG bit-stream for the considered MB.

Step 5 : Repeat steps 1~3 for each MB in the considered I-frame.

Step 6 : Repeat steps 1~4 for the next I-frame.

Fig. 2 shows an example for embedding "1" by considering only two 8×8 blocks. Figs. 2(a) & 2(b) represent original quantized DCT coefficients in Ω_A and Ω_B, respectively. By calculations, we obtain $E_A = 5$, $E_B = 30$, $E_d = E_A - E_B = -25$. Assuming w = "1" and $\beta = 0$, case 3 in step 3 is satisfied and nonzero coefficients in Ω_A and Ω_B should be modified by $q_A = 4$ and $q_B = 3$ (with $n_A = 4$, $q_{Ai} = 4$, $n_A^+ = 0$, $m_A = 11$, $n_B = 9$, $q_{Bi} = 2$, $n_B^+ = 5$ $m_B = 4$) to obtain $E'_A = 21$ and $E'_B = 12$, which leads to $E'_d = E'_A - E'_B = 9 > 0$, as shown in Fig. 2(c) and (d). It is found that there will still have an energy margin between E'_A and E'_B after coefficient modifications even β is set to 0, since q_A and q_B may be over-estimated due to the ceiling function $\lceil\ \rceil$.

For security consideration, orders of watermark bits can be pre-randomized by a key which should be provided in watermark retrieval.



(a) $d_{QA(x,y)}(k,l)$ (b) $d_{QB(x,y)}(k,l)$ (c) $d'_{QA(x,y)}(k,l)$ (d) $d'_{QB(x,y)}(k,l)$

Fig. 2. Modification of coefficients when embedding "1".

2.2 Retrieving Scheme

To retrieve the watermark bit w embedded in an MB, we simply calculate E''_A, E''_B, and E''_d as in *Step 1* above :

$$E''_d = \sum_{(k,l)\in\Omega_A} \left| d''_{QA(x,y)}(k,l) \right| - \sum_{(k,l)\in\Omega_B} \left| d''_{QB(x,y)}(k,l) \right|$$

where the doubly primed terms represent quantized DCT coefficients decoded from the test bit stream. The judging criterion is simple :

$$\text{if } E''_d \geq 0 \text{ then } w = \text{“1”, else } w = \text{“0”}.$$

Since we may have embedded multiple copies of each watermark bit w_i in the whole video, the rule of dominance can be used for final decision, i.e.,

$$w_i = 1, \quad \text{if } \sum B(e_{ik} = 1) \geq \sum B(e_{ik} = 0),$$
$$w_i = 0, \quad \text{if } \sum B(e_{ik} = 1) < \sum B(e_{ik} = 0),$$

where e_{ik} represents the k-th instance of extraction for watermark w_i and B( ) is a Boolean function that returns $B(True) = 1$ and $B(False) = 0$.

3. EXPERIMENTS AND EVALUATIONS

To evaluate performance of proposed video watermarking algorithm, four MPEG-2 video “Susi”, “Akiyo”, “Cactus”, and “Table tennis” (3M bps, 352× 288 pixels/frame, 30 Hz, 100 frames), were used as the hosts for embedding a watermark of 396 bits. Obviously, one set of watermark can be exactly embedded into an I-frame and multiple embedding is performed over the whole video. Performance of de-watermarking is indexed by a correlation value ρ between the original and the extracted watermarks, which is defined to be

$$\rho = \frac{\textit{number of correctly identified watermark bits}}{\textit{number of watermark bits}}$$

Table 1 compares our proposed and Koch et. al's [3] methods in file size change after watermarking. It can be found that Koch's method always has an increase in bit length (+135.25 bytes on average), while our method is video-dependent and decreases bit length by 23.25 bytes on average (hence revealing a closer bit rate to the original video after “transcoding”).

Table 1. Change of bit-stream length after watermarking.

Method	MPEG video	Encoding bit-rate (bps)	Change in file size (bytes)
Proposed	Susi	3M bps	-282
	Akiyo		174
			88
	Table tennis		-73
E. Koch & J. Zhao [3]	Susi		147
	Akiyo		153
	Cactus		76
	Table tennis		165

Table 2 shows average PSNR performance for each frame in a GOP structure. It can be seen that both the Koch's and proposed methods cause few and graceful drift errors in decoded P and B frames (except #2~#4). Though our method yields slightly more PSNR degradation due to a greater change in quantized DCT coefficients, the visual quality is better (nearly no display flicker or fluctuation) according to several subjective human tests. This may be owing to spread distribution of energy added in the compressed domain. On the contrary, a textured effect can be seen when the Koch's video result is playing.

Table 2. PSNRs in a GOP after watermark embedded in the I-frame.

Display order	Before watermarking (dB)	After watermarking (dB)		Change in PSNR (dB)	
		Koch	Proposed	Koch	Proposed
1 (I)	53.28	48.73	49.11	-4.55	-4.17
2 (B)	51.92	51.46	50.79	-0.46	-1.13
3 (B)	53.43	52.92	52.92	-0.51	-0.51
4 (P)	51.33	50.49	50.36	-0.84	-0.97
5 (B)	53.01	52.82	52.82	-0.19	-0.19
6 (B)	52.86	52.75	52.78	-0.11	-0.08
7 (P)	52.77	52.70	52.72	-0.07	-0.05
8 (B)	52.44	52.42	52.43	-0.02	-0.01
9 (B)	52.22	52.21	52.21	-0.01	-0.01
10 (P)	52.04	52.01	52.03	-0.03	-0.01
11 (B)	52.82	52.72	52.63	-0.1	-0.19
12 (B)	53.12	53.04	52.98	-0.08	-0.14
average				-0.58	-0.62

Based on the video quality of no human-perceptible display flicker and texture, we evaluate robustness of the proposed algorithm by conducting "re-encoding" attack. It is possible that pirates decode the received bit-stream and then re-compress them with a coarser quantization (i.e., at a smaller bit-rate). This attack may damage or remove the embedded watermarks. By experiments, it is found that the retrieved watermarks maintain over 70% of correctness with the originals when re-encoding target bit-rates was (from 3M bps) down to 0.5M bps, as shown in Fig.3. Fig. 4 also compares robustness against re-encoding attack for our proposed and Koch's [3] methods on the "Susi" video with comparable PSNR performance. The results obviously reveal superiority of our algorithm. Similar performance also exists for the other three test videos.

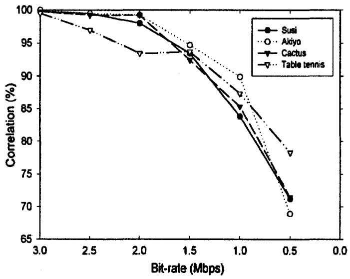


Fig. 3. Evaluation of robustness against re-encoding attack (β=0).

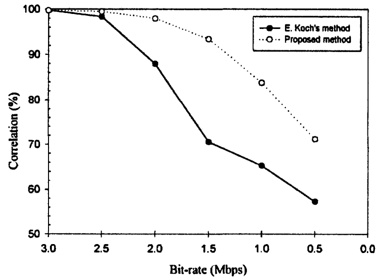


Fig.4. Comparison of robustness between proposed and Koch's methods for re-encoding attack on "Susi" video with comparable PSNR performance.

It may be improper to judge video watermarking quality solely based on the objective measures (e.g., PSNR) of individual frames. Actually, improper schemes may cause a flickering effect in the watermarked video even with a high PSNR quality. Hence, we conducted a subjective test for our proposed method. A number of 15 persons were requested to judge the superiority between two unlabeled video sequences (one original and one watermarked). Statistics in Table 3 show that over 80% (12/15) of testers can not distinguish the watermarked videos from the original ones and even make false decisions.

Table 3. Subjective test for the proposed method.

Video	Correct identification	Wrong identification	undistinguishable
Susi	0	3	12
Akiyo	1	2	12
Cactus	0	3	12
Tennis	2	0	13

Since our proposed scheme extracts watermarks based on the energy difference between two selected regions, it is likely that the extracted bit pattern from a unwatermarked video may be highly correlated to the true watermark and results in a false alarm. We test I-frames of 6 unwatermarked videos and compare the extracted bits with those previously embedded in experiments (basically, random bits). Results shown in Fig.5 reveal that the correlation values are all between 45%~55%, implying randomness of the extracted bits.

Practically, a threshold T is set on ρ to determine watermark existence. Lower T will result in stable identification even with severe attacks (e.g., low bit rate compression). However, this will no doubt increase the false alarm rate. A proper threshold can be determined empirically or by using pattern classification technique. From Fig.5, T = 60%~70% will maintain a low false alarm rate while maximizing the robustness against attack.

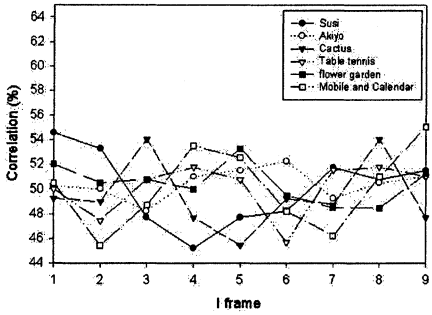


Fig.5. Correlation tests with unwatermarked videos.

4. REMARKS AND CONCLUSIONS

In this paper, we have proposed an effective DCT-based compressed-domain watermarking scheme for multimedia copyright protection and authentication. Our algorithm is featured of :

(1) in contrast to traditional methods that focus on embedding watermarks in unquantized DCT domain,
(2) suitable to most network transcoding applications that accept compressed data, instead of the raw data, as input,
(3) simple watermark embedding and retrieving schemes,
(4) being blind, i.e., requiring no original video data for watermark retrieval,
(5) high robustness to re-encoding (re-quantization) attack,
(6) a least variation in bit rate after watermarking.

Comparing to a previous work [4] for image watermarking in the unquantized DCT-domain, the present result is somewhat limited. The need of 4 blocks (i.e., 1 MB) for 1-bit embedding prevents the implementation of "multiple embedding" in a single frame for more robustness. The embedding capacity is much less than that (8 bits/block) can be achieved in [4] (however still 4 times larger than [6] which uses 16 blocks for 1-bit embedding). This low-capacity characteristic seems common to most compressed-domain watermarking algorithms, owing to many zeros in quantized DCT coefficients.

Our future work will focus on four main issues :

(1) consideration of HVS (human visual system) to further improve visual quality and also enhance embedding capacity,
(2) extension of the algorithm to embed watermarks in P and B frames,
(3) finding solutions to advanced attacks such as frame cropping and dropping,
(4) integration into transcoder design for video streaming application.

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